High Energy Density Laboratory Plasmas
Introductory Remarks

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OFES Budget Planning Meeting

www.ofes.fusion.doe.gov

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Current OFES research in HED plasmas

- Scientific Themes
  - Develop the physics basis of pulsed, high density approach to fusion energy by studying HED plasmas
  - Create, probe, and control new states of HED plasmas
- Research covers fundamental areas of HEDLP physics
  - Warm dense matter
  - Laser-plasma, radiation-matter interaction
  - Relativistic plasmas
  - Dense plasma in high magnetic fields
  - Compressible, radiative MHD
- Conducted in the context of three applications in IFES
  - Heavy ion fusion
  - Fast and shock ignition
  - Magneto-inertial fusion

HED projects in the past ICC program have been consolidated to the Joint Program in HEDLP in FY 2008

- HED ICCs consolidated into the Joint Program in HEDLP
  - Form the core of the program in dense plasmas in high magnetic fields (magnetized HEDLP):
    - Solid-liner MTF
    - Plasma-jet driven MTF
    - Dense-plasma wall interactions
    - Magneto-kinetic compression of FRC
    - Staged Z-pinch
- In addition, the SSPX group at LLNL has been re-directed towards a program in fast ignition and HED science to take advantage of major NNSA facilities.

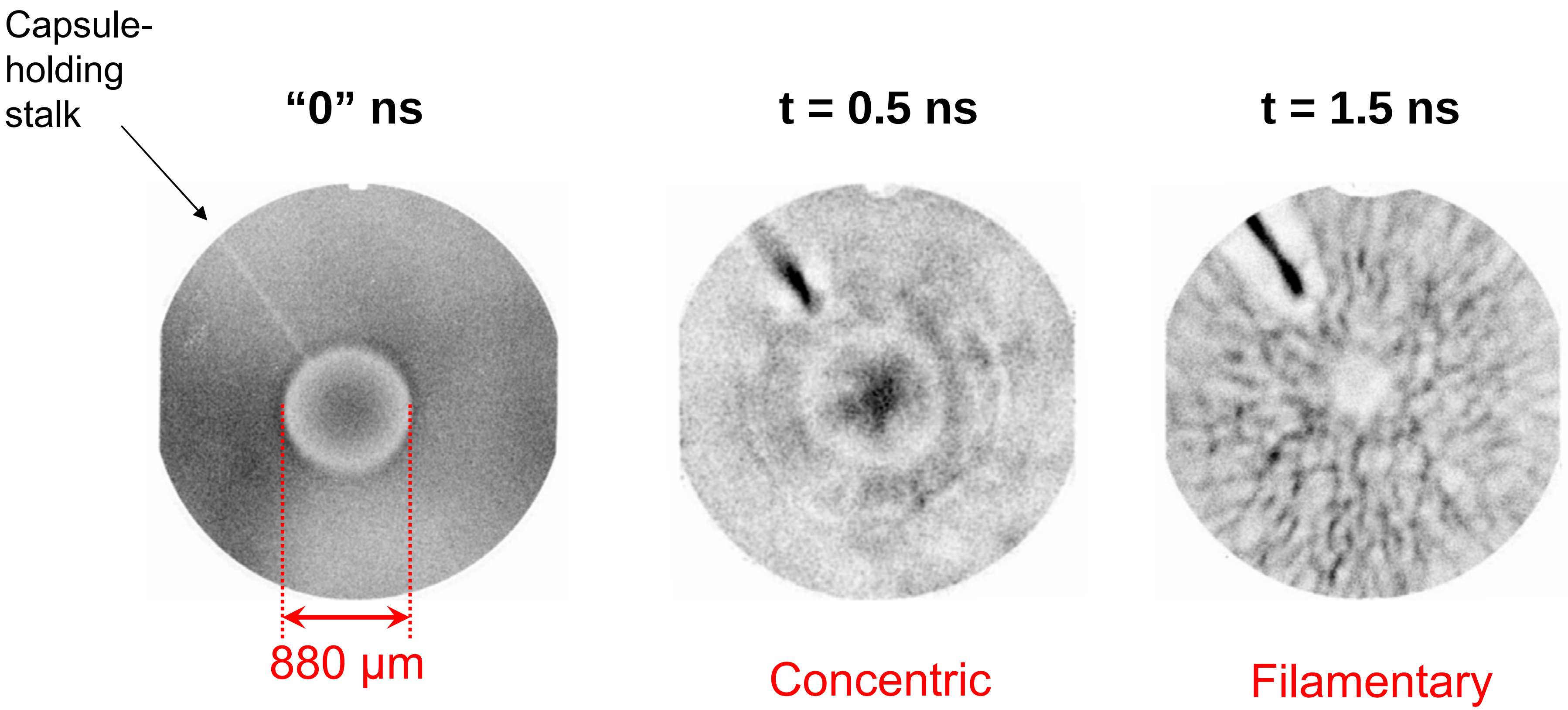
With the limited funding at present, the OFES focus in IFES related HED research is modest ……

- In particular, we focus on studying ways to lower the implosion velocity and increasing coupling efficiency as one avenue towards higher fusion gain-efficiency product, while achieving ignition
  - Long-term, IFES requires higher gains, suitable targets and drivers, at reasonable costs
- Addressing the physics basis for three different approaches to achieve lower implosion velocity and higher coupling efficiency
  - Decoupling ignition from fuel assembly so that the dense fuel can be assembled with low implosion velocity and low adiabat
    - Fast ignition, shock ignition
  - Embedding an intense magnetic field in the target to slow down thermal losses from the hot spot, thus lower the implosion velocity required
    - Magneto-inertial fusion (magnetized target fusion)
  - Heavy ions have potentially higher efficiency in coupling to the target hydro
    - Heavy ion fusion

Characteristics of Current OFES Research in HEDLP

- Despite its energy-applications-related orientation, the research has the following three attributes
  - Research is fundamental HEDLP
    - Advancing frontiers of HED plasma science
  - Research is discovery driven
  - Research is use inspired
    - Develop the HED plasma physics basis for IFES
    - Applications potentially of extremely high value for humanity

15 MeV proton radiographs show radical changes in the topology of strong fields during ICF implosions

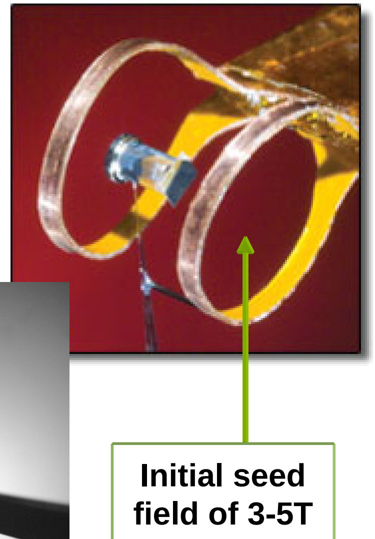


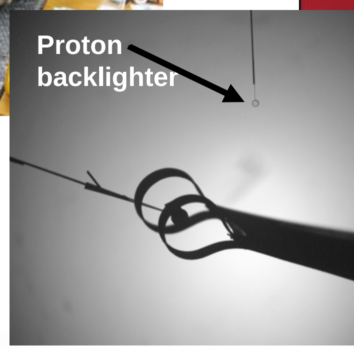
Seguin *et al.*, to be published

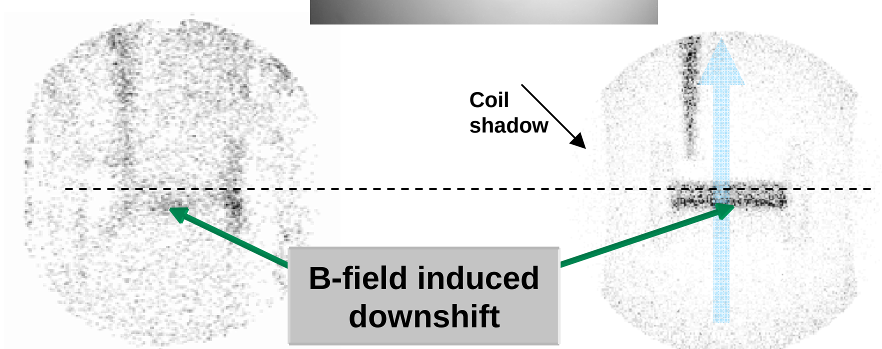
Magnetic flux compression in MIF implosion experiments on OMEGA

Proton deflectrometry measurements show B-field compressed to ~1300T

MIFEDS field generator

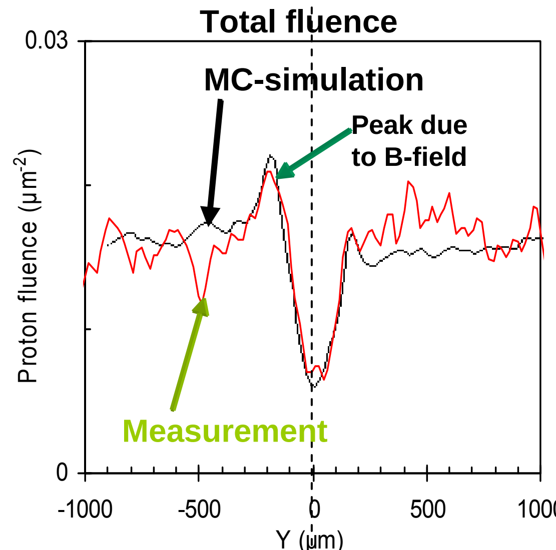


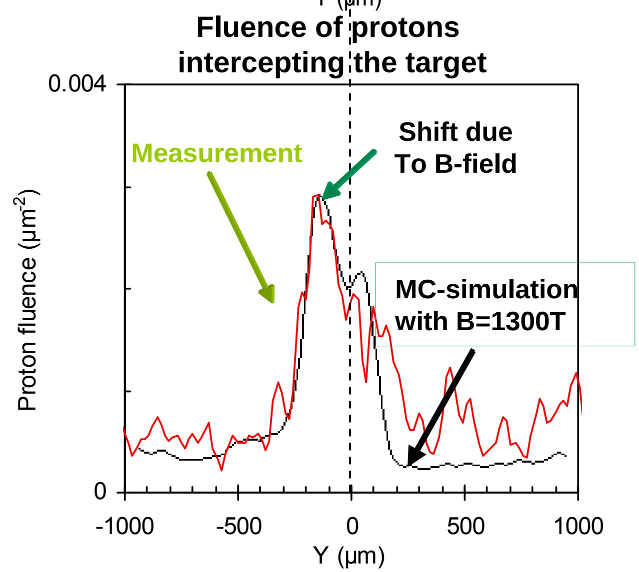




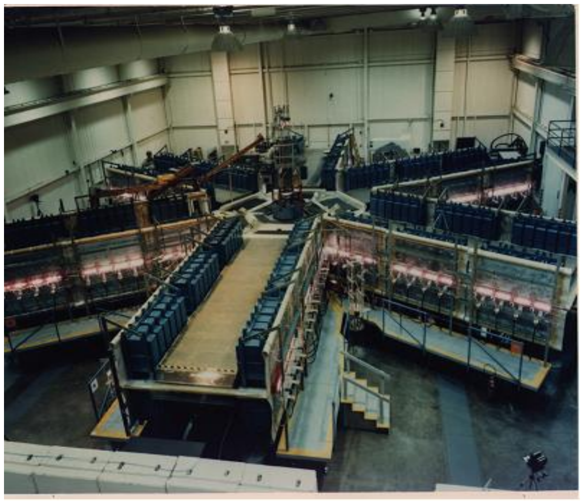
Proton density map (E_{kin} < 14.8 MeV) at the detector surface

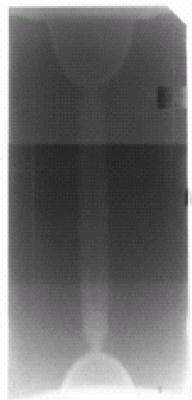
Simulated proton density map (E_{kin} < 14.8 MeV) at the detector surface





Multi-MJ pulsed power facilities ready for implosion experiments for magneto-inertial fusion (MIF) research



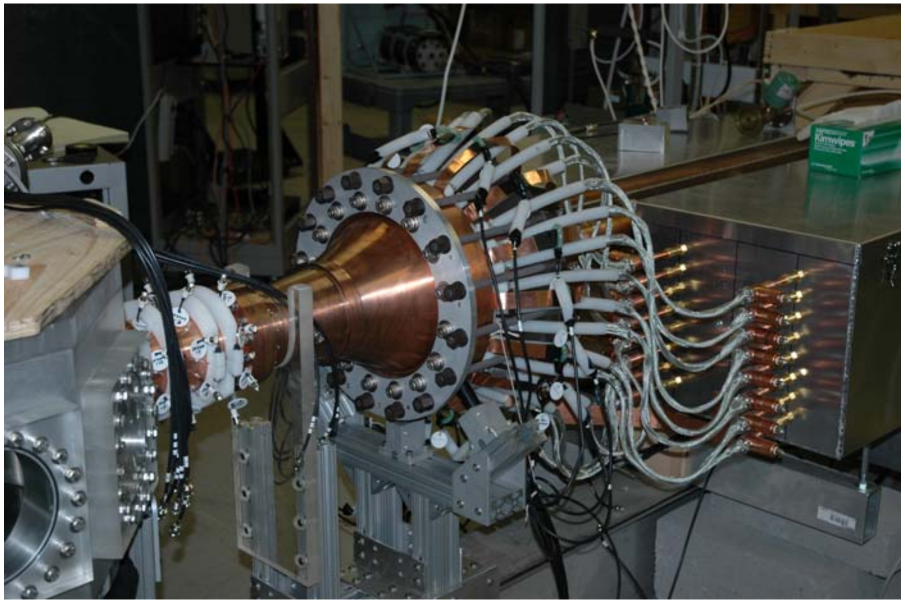


- **Solid liner technology is now ready to implode magnetized targets**
- imploded a 30-cm long, 10 cm diameter, 1.1 mm thick Al liner in 24 μs reaching 0.5 cm/μs, with 16x radial convergence
- ***Integrated MIF implosion experiment to begin in 2008***

Magnetized target is ready to be imploded

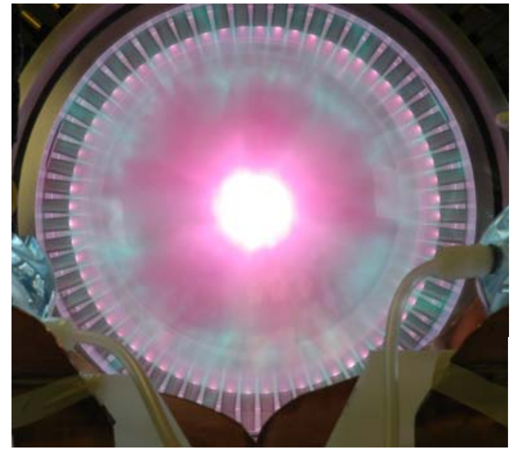
Demonstrated FRC ~ 5 x 10^{16} cm^3, 300 eV, ~ 10 μs

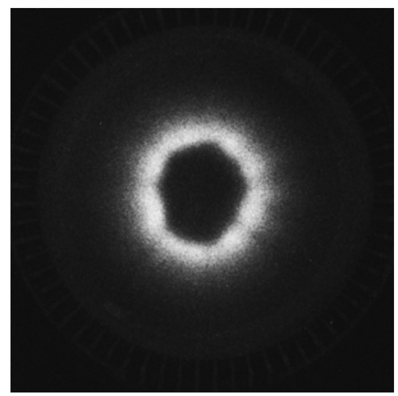
Major breakthrough in plasma jet research

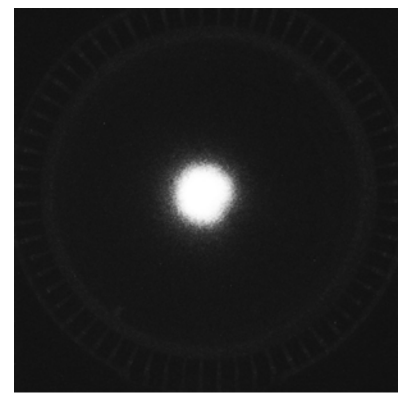


Advanced plasma gun has launched 160 μg of high-β (β >>) 1 plasma to 85 km/s

Community is ready to conduct a major experiment to merge full-scale plasma jets to form plasma liner





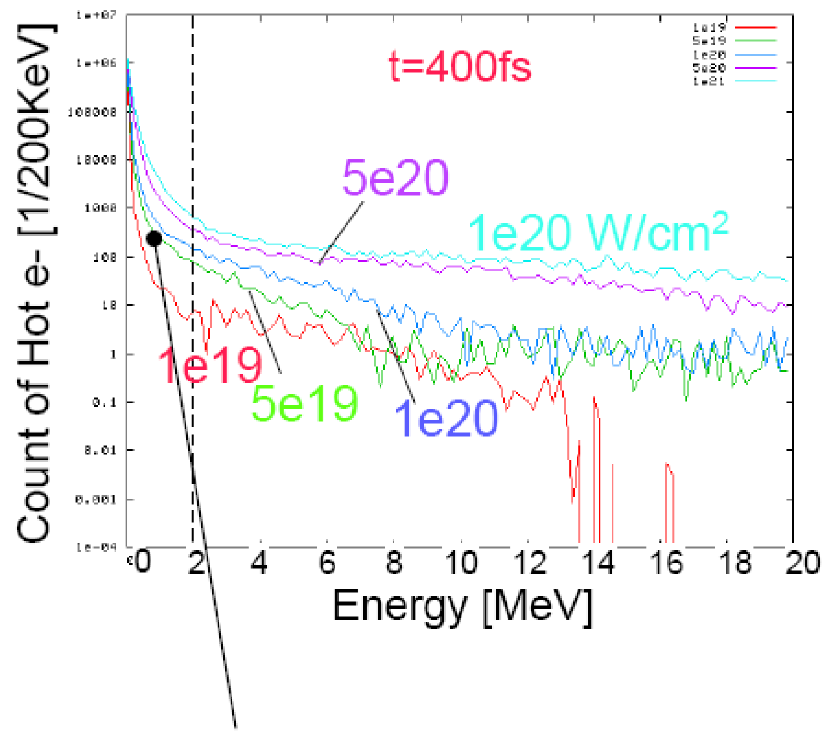


Formation of plasma ring by merging of 2π array of mini-plasma jets has been demonstrated

Laser-matter interaction in the relativistic regime

- Early evidence that light pressure effect reduces electron energy
- New diagnostics to measure electron spectrum in the target through bremsstrahlung
- Preliminary results on Titan suggest light pressure effects are significant.

Spectrum observed behind cone.



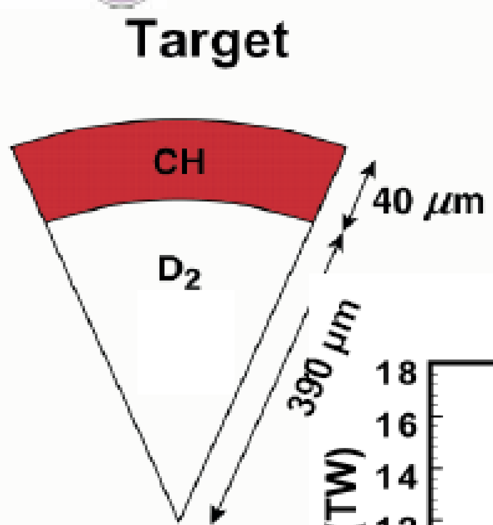
Low energy hot electrons (<2MeV) increase linearly with intensity.

FY09-10 plans:
Improve Brem. diagnostic
Electron energy spectrum measurements on Titan and EP

The shock ignition concept has been tested on OMEGA

FSC

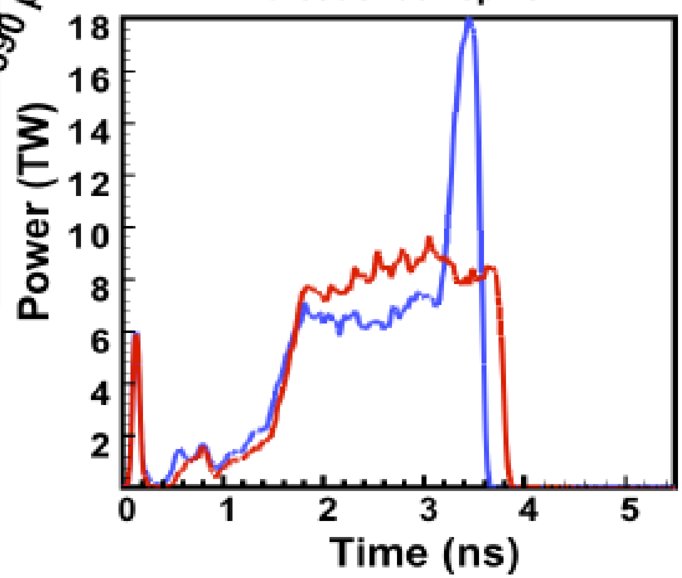
UR LLE

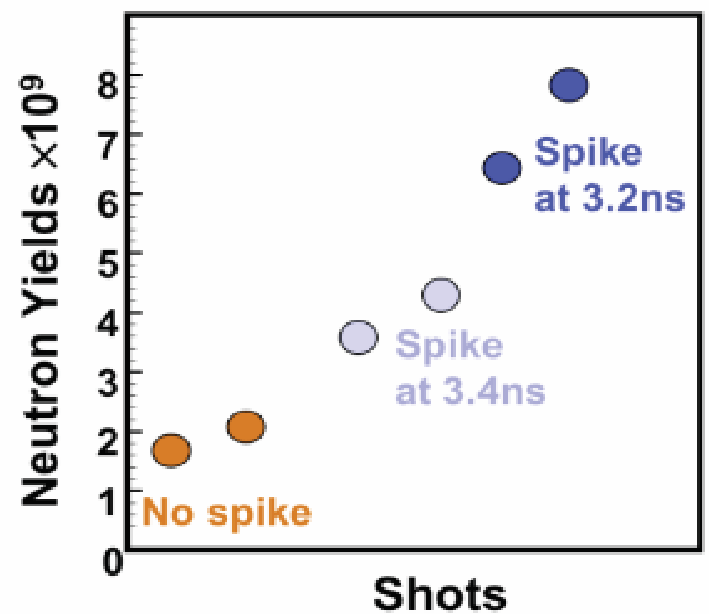


W. Theobald,
R. Betti,
C. Zhou,
C. Stoeckl
(UR-LLE)

E_L=17-18kJ
$\alpha\approx$1.3

Pulse shape with and without shock spike





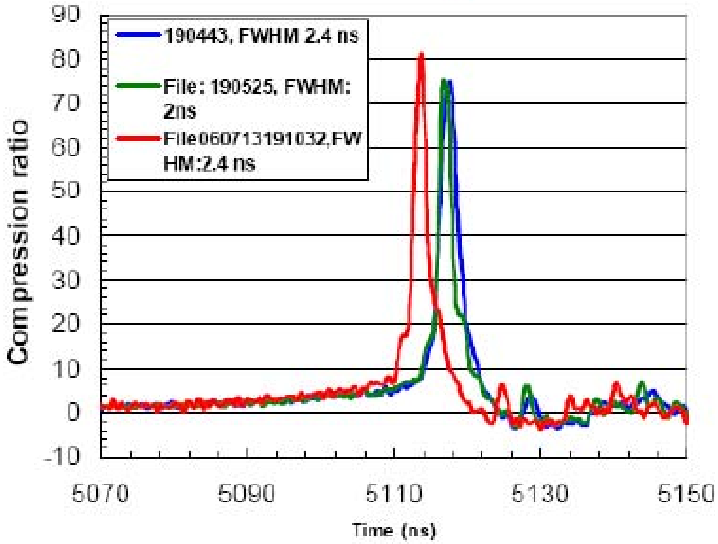
The neutron yield increases considerably when a shock is launched at the end of the pulse

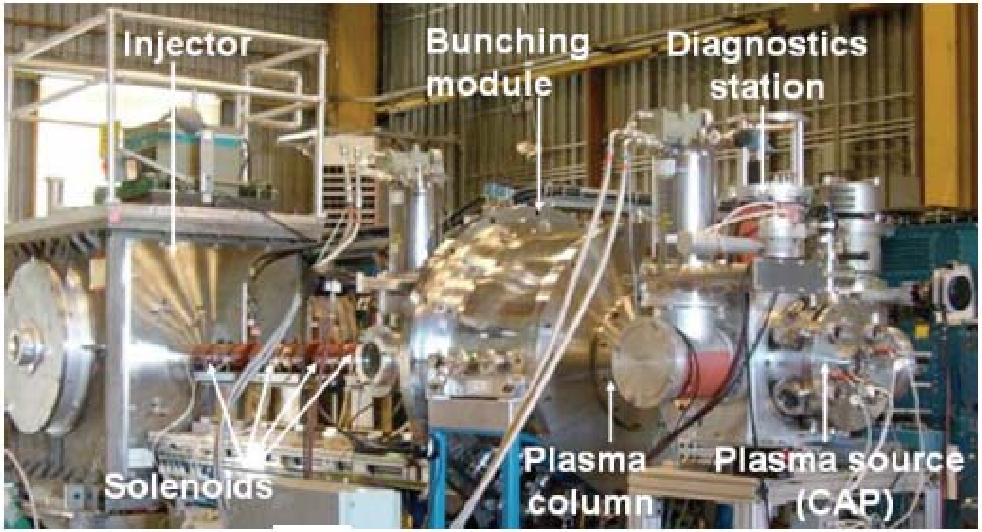
More experiments with CH targets in ’07-’08, cryo-targets in ‘09

R. Betti, FO 1.3, “Shock Ignition of Thermonuclear Fuel with High Areal Density”

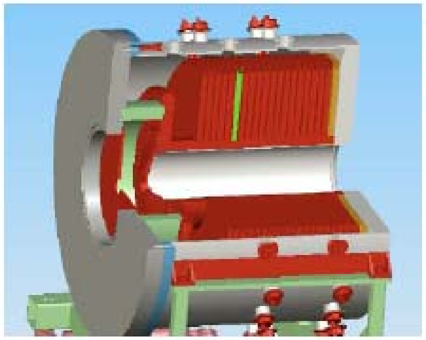
Neutralized Drift Compression of ion beam has been demonstrated and ready to be implemented

Shorter pulses (2.4 ns) obtained w/ new Ferro-electric plasma source

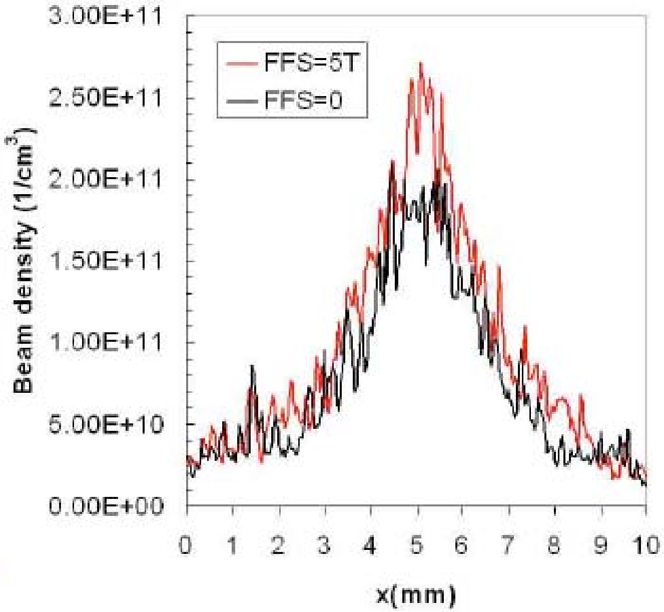




Simulations predict higher compression with new induction buncher



First combined radial and longitudinal compression: to be repeated with more plasma for better beam neutralization



Scope of the Joint Program in HEDLP

- Central hot-spot ignition, fast ignition, shock ignition, laser-plasma and radiation-matter interaction
- Inertial fusion with magnetized targets, plasma jets, dense plasmas in high magnetic fields
- Inertial fusion with heavy ion
- Warm dense matter
- High energy density laboratory astrophysics
- Fundamental properties and behavior of high energy density plasmas

OFES Lead **NNSA Lead** **Equal share between OFES and NNSA**

Summary

- Current OFES interest emphasizes IFES-motivated HEDLP, but plans to expand program to include HED astrophysics that most overlap with this portion of the HEDLP space.
  - Complements NNSA's interests and stewardship of HEDLP
- Limited funding at present forces OFES to adopt a modest approach and focus on pursuing research in optimizing gain-efficiency product for IFES
  - Lowering implosion velocity and increasing coupling efficiency
  - Decoupling ignition from fuel assembly
  - Suppressing thermal transport by embedding an magnetic field in the target
  - Increasing coupling efficiency by using heavy ion beams
- The research covers the fundamental areas of HEDLP in:
  - Warm dense matter
  - Laser-plasma, radiation-matter interaction
  - Relativistic plasmas
  - Dense plasma in high magnetic fields
  - Compressible, radiative MHD

Presentations on Energy-Related HEDLP:

This is the charter for the OFES role in the Joint Program according to the President's Budget RequestS of FY 2008 and FY 2009

- Grant Logan – Heavy Ion Fusion and Warm Dense Matter
- Riccardo Betti – Fast Ignition, Shock Ignition, Laser-Plasma Interaction, Radiation-Matter Interaction, Relativistic Plasmas
- Scott Hsu – Magneto-Inertial Fusion and Dense Plasmas in High Magnetic Fields

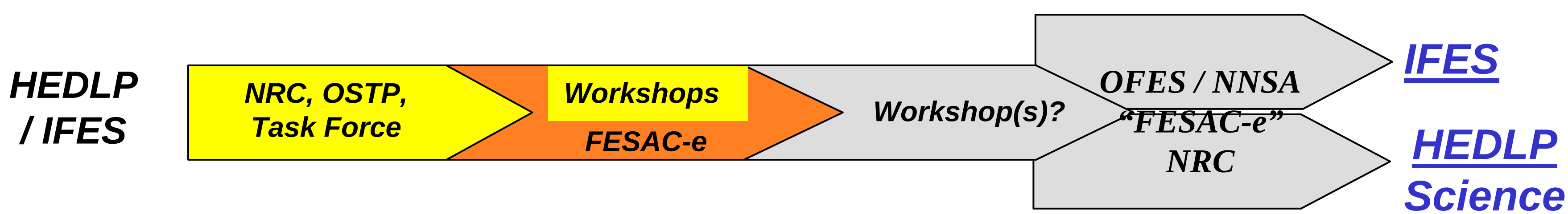
Presentation on Non-Energy Related HEDLP to be given by Dave Hammer and Bedros Afeyan

- An area of HEDLP that has been cultivated and sponsored by NNSA
- NNSA’s primary interest in the Joint Program is HEDLP related to stockpile stewardship
- NNSA’s secondary interest is any area of excellence in HEDLP science that can provide development of its future workforce
- OFES is its new vision has aspiration to be a steward of Plasma Science and High Energy Density Laboratory Plasma physics
  - Aspires to expand its interest in the Joint Program into non-energy related HEDLP
- How funding for this area of HEDLP be generated requires much further deliberation between the two Offices
- HEDSA has been invited to provide the community inputs

Back-up Slides

Joint Program in HEDLP

- OFES interests in the Joint Program
  - Improve stewardship of Federal Government HEDLP program
  - Energy-related HEDLP studies to support case for IFES research in future
- Interested in exploiting scientific opportunities in large NNSA facilities
- Competition and diversities will be encouraged in the program
- Planning follows same paradigm as for other OFES planning activities
  - FESAC to inform development of HEDLP program scientific roadmap for the next decade
  - Expect to follow with Workshop and consolidation of issues



HEDP-Research Topics & Related Federal Research Categories

Federal Research Categories	Research Examples
Astrophysics (NASA, NSF)	Astrophysical jets Neutron star interiors Core-collapse supernovae
High Energy Density Nuclear Physics (DOE/NP)	Quark-gluon plasmas; Nuclear astrophysics
High Energy Density Laboratory Plasmas (DOE/NNSA, DOE/FES)	**Radiative hydrodynamics** **Laser-plasma and beam-plasma interaction** **Fusion burn** **Materials under extreme conditions** **Dense plasmas in ultrahigh fields** **Laboratory astrophysics**
Ultrafast, Ultraintense Laser Science (NSF, DOE/BES)	Ultraintense x-rays for material science studies; applications of ultraintense lasers to chemistry and materials; advanced accelerators

Current OFES Research in HEDLP

- Warm Dense Matter (Heavy ion fusion)
  - $8.14M, 5 grants, 3 labs, 1 university, 1 industry
- Laser-plasma, radiation-matter interaction and relativistic plasmas (fast Ignition, shock ignition)
  - $5.4M, 9 grants, 4 labs, 5 universities
  - $1.1M, Fusion Science Center at U. Rochester
- Dense plasma in high magnetic fields, compressible, radiative MHD (Magneto-inertial fusion, astrophysical jets, and other)
  - $4.71M, 17 grants, 4 labs, 10 Universities, 4 industries